EMBO reports

analysis

Kitchen biology

The rise of do-it-yourself biology democratizes science, but is it dangerous to public health and the environment?

Even before university science departments became universally strapped for cash in the current financial crisis, researchers could already buy and sell laboratory equipment on Internet auction sites. The availability of this equipment, coupled with the increasingly lower costs of consumables for DNA extraction and testing, has given rise to a movement of skilled and non-skilled enthusiasts who are conducting molecular biological experiments at home in their kitchens. Yet, some legislators and scientists worry that do-it-yourself (DIY) biology might pose a danger to public health and environmental safety, and that unregulated experiments conducted in kitchens and garages might accidentally or intentionally unleash biological disaster.

Despite the concerns, the DIY biology movement has certainly sparked the imaginations of many hobbyists, who argue that taking ownership of their own biology, and demystifying the science behind genetic and medical tests is empowering. Debra Katz, for example, who calls herself 'DNA Deb' in her e-mails, has spent thousands of dollars over the past nine years on analysing her own DNA for genealogical purposes. Katz is an administrator for the city of Palo Alto (CA, USA) and, although she has no scientific background, she was recently able to extract her own DNA in her kitchen using instructions downloaded from About.com, and beakers and test tubes that she bought for less than US$20.

Katz said that extracting her DNA "[…] was not hard at all. I was getting a kick out of trying to be Ms Science." She noted that although she had no interest in science during her high-school and college years, conducting this particular procedure herself connected her intellectually with her genetic-genealogy work and helped to make DNA more real for her. "[I am interested] in the results of analysing DNA, so it just seems like a fascinating tangent to actually see my DNA physically. [W]hen you do the testing with the labs, whether you send in spit or rub your cheeks, you don't see anything," she explained.

Kay Aull, a graduate of the Massachusetts Institute of Technology (MIT; Cambridge, MA, USA) with a degree in biological engineering, has similarly embraced DIY science, even taking it to the next level. She has been analysing her own DNA at home to see whether she is a carrier of the disease haemochromatosis, from which her father suffers. Haemochromatosis is characterized by increased iron absorption in the liver, pancreas, skin and other organs, and Aull could have spent approximately US$300 to have a laboratory test for the presence of high-risk mutations (Wolinsky, 2005). As Aull noted, however, sending your samples to a laboratory is "old school." Instead, for roughly the same amount of money, she obtained some specialized laboratory equipment—including a polymerase chain reaction machine that she purchased on eBay for US$59—and some regular kitchen equipment, and performed the tests herself.

"I'm a hacker. I like to build stuff," she explained. "Biology is a great system to explore and understand." In fact, her DIY

test showed that she has at least one copy of the high-risk mutation, C282Y, although she noted that, "[t]here's still a control that didn't come out clearly, so I'll be repeating it when I get my nice new gel box […] [a]nd then repeating it professionally once my health insurance is in place." She explained that there is power in knowing the test results: "This disease is completely treatable if caught early, and now I can monitor it proactively instead of waiting to get sick."

Katz and Aull are both part of a growing movement of amateur molecular biologists, and, as such, are part of a long tradition of science enthusiasts that includes amateur ornithologists, archaeologists and astronomers. Indeed, as Aull quipped, "[e]veryone needs a hobby"; however, she also pointed out that DIY biology represents something much more than a hobby: it democratizes science and gives people access to their own biological data in the most direct way possible.

Jason Bobe, Director of Community for the Personal Genome Project, which is part of the George Church laboratory at Harvard Medical School (Boston, MA, USA), is also one of the co-founders of a Boston-based organization called DIYbio (http://diybio.org) that, "aims to help make biology a worthwhile pursuit for citizen scientists, amateur biologists, and DIY biological engineers who value openness and safety." DIYbio has more than 800 members, each of whom typically orders kits from educational supply warehouses to amplify and even analyse their own DNA using equipment purchased on eBay or Craigslist.

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Bobe compares the DIY biology movement to hobbyist high-powered rocketry—explosive physics in the backyard—and is sure that kitchen biology will increase in popularity. "There's no doubt that there will be more over-the-counter biology kits that are self-contained and generally recognized as safe. There are already half a dozen of these out there for even doing genetic engineering," he commented, noting that the DIY molecular-biology movement is partly the result of the increasing availability of materials and tools. "As the price drops, more individuals are going to be managing their own biology and biological data and utilizing tools that were once the purview of the professional bioinformatic folks," he said. "New communities of individuals will build up around these things outside of the professional settings—that whole transformation is going to happen again in other areas of biotechnology."

Another co-founder of DIYbio is MacKenzie Cowell, who previously helped to run the International Genetically Engineered Machine competition (iGEM; http://2009.igem.org) at MIT. He pointed out that many of the amateurs now involved with DIYbio have technical backgrounds and want to get more involved in hands-on science. He said, for example, that some of the bioinformaticians that he has met in Boston are tired of only making predictions: "They actually want to start doing physical biology instead of computational biology […] Some say: 'It's my turn. I want to roll up my shirt sleeves and get my hands wet: do some wet work.'"

Indeed, the DIY-biology movement takes inspiration from the iGEM competition, in which student teams are given a set of biological parts—selected from the MIT Registry of Standard Biological Parts (http://partsregistry.org)—and must use them, along with parts of their own design, to build biological systems that operate inside living cells. The iGEM competition grew from 4 teams and 16 students at MIT in 2003 to 84 teams with 1,200 participants from 21 countries in 2008. Randy Rettberg, iGEM's Director and Principal Research Scientist at the MIT Computer Science and Artificial Intelligence Laboratory, compares the iGEM to robotics competitions. He said that the competition is gaining attention from students around the world who want to learn about synthetic biology and engineering biological systems.

Bobe commented that it is inspiring to see students with little training in biology in action. "Some of them are freshman and [are] developing vaccines or biofuels. What can be more exciting than seeing that?" he said. "You know, it's one part inspiration and one part accessibility to these technologies [that can] hopefully inspire a whole new generation to get excited about biology and technology and all sorts of things." Physicist-turned-bioentrepreneur Robert Carlson, who founded the biotechnology firm Biodesic (Seattle, WA, USA), similarly regards the DIY biology movement as a positive development. "The greater the proliferation of knowledge, the better informed everyone is. You don't have to be scared of DNA; you're full of DNA. You can extract your own DNA and see what's there and you can do restriction analysis on your own DNA and correlate that with certain traits or diseases," he said.

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Carlson also expects economic benefits to come from DIY molecular biology, similar to the emergence of Silicon Valley as an engine of innovation resulting from the work of computer hobbyists experimenting in their garages. "We're just seeing the beginning of it," he said. "I think it's going to grow like the iPhone app market, which exploded overnight. […] I'm not trying to argue that synthetic biology or DIY [biology] is going to have the same impact as does recombinant technology, but costs are falling exponentially for genes and for sequencing and productivity is improving exponentially in both synthesis and sequencing. It's a few thousand dollars today to buy a gene that you've designed, and in a couple of years, it will be a few hundred dollars if the trends continue."

Although advocates emphasize the educational value and economic potential of DIY biology, some security analysts worry about the prospect of possible abuse for nefarious purposes. "Experimentation with living organisms—particularly pathogenic organisms—is problematic because they are self-replicating and transmissible, so they pose many hazards that one would not encounter in many other types of do-it-yourself science," commented Jonathan Tucker, a Senior Fellow at the James Martin Center for Nonproliferation Studies at the Monterey Institute of International Studies (Washington, DC, USA). "We have to think very carefully about how this type of amateur science should be regulated to protect the

individuals doing the work and also society as a whole."

According to Tucker, part of the problem is that amateur science is moving faster than regulators and legislators. "There has been some discussion of regulating synthetic biology in academic laboratories and industrial laboratories, but there's been very little discussion of amateur science," he said. Tucker contends that young people have latched on to the DIY approach because of "the gee-whiz factor." "It's gotten a lot of publicity, much in the same way that computing a generation ago captured the imagination of young people. The next new thing is synthetic biology," he said. However, he also noted that DIY biology, similar to computing, is a double-edged sword: it has the potential both to benefit society and to cause much harm—if the people using DIY biology do so for malicious purposes, including criminal activities and terrorism.

"We have to be aware and not be naive about the potential for misuse of this technology, particularly if it's going to be democratized in the way that the DIY visionaries would like," Tucker commented. "I think government has to intervene in the interests of protecting society, not only from deliberate misuse, but also [from] the inadvertent hazards that could be created with this technology. […] [W]hen people start assembling complex systems that involve tens to hundreds of genes from a variety of different organisms, those types of experiments outstrip the current biosafety paradigm. There could be unpredictable effects and interactions that might result in self-replicating organisms that escape into the environment and cause ecological damage and even public health threats […] we should not be as casual about the risks as I believe the DIY biologists are."

The US government has been concerned about home-grown bioterrorism ever since the anthrax terrorist attacks in 2001. Steve Kurtz, an Art Professor at the State University of New York at Buffalo (NY, USA) and founder of the performance-art group Critical Art Ensemble that used DNA and other biomaterials to encourage a political debate, was arrested when laboratory equipment and harmless bacteria were found in his house in 2004. The equipment was discovered when the emergency services responded to his call for help when his wife died at home from heart failure. The Federal Bureau of Investigation came to the house dressed in biohazard suits and arrested Kertz, who was initially charged with bioterrorism, but was only indicted for mail and wire fraud. A federal judge dropped the charges in 2008 (Associated Press, 2008). Indeed, in the recent past, the perception of biological security risks seems to have decreased. "There's a bit of a different vibe culturally now about this stuff than there was in, say, 2001, right in the middle of the anthrax scare," Carlson commented.

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Cowell is also sceptical about whether the DIY-biology movement will be a school for terrorists, and made the point that with or without amateur groups such as DIYbio, terrorists are going to find ways and means to gain the knowledge, equipment and skills that they need to conduct their illegal activities. "[E]nabling more people to do biology isn't necessarily going to be the bottleneck. By stopping amateurs, that doesn't really stop terrorists," he said. He also commented that most amateurs are interested in working at or below the hazard classification level BL-1, which is the least dangerous level of biological experimentation. "At that level, the reason you have a lab isn't to protect the world from your stuff. It's the other way around. The cells you're working with are so fragile that you can't really do an experiment if there is any kind of contamination," he said.

According to Bobe, amateur rocketeers have managed to allay concerns about public safety and national security through a combination of practitioner certification and cooperation with federal oversight bodies, which Bobe believes is the right path forward for DIYbio. However, he acknowledged that the extent of regulation necessary to achieve public safety is unclear and noted that the rocketry community has just emerged from a nine-year legal battle with federal authorities over access to fuels. "There are going to be the same types of challenges with DIYbio and it will be a good thing to monitor the types of synthesis activities that people are doing. A framework needs to be built," he said. "High-powered rocketry has it figured out. There's certification. The more advanced the rocketry you do, the more certification you need to get. […] In the absence of anything like that, DIYbio is just left to people's imaginations." He said that DIYbio favours the "development of a code of ethics, responsible oversight, and leadership on issues that are unique to doing biology outside of traditional professional settings."

Carlson also conceded that DIY biology has the potential to go wrong, although he is cautious of too much regulation. "There is probably risk now and it will grow, but you also have to ask what happens if you regulate […] There are plenty of historical examples of what's happened to markets for distributed technologies when proscription or prohibition is implemented. I use the word prohibition quite intentionally: we have a very clear experience with what happened in this country when [fermentation] was proscribed in the 1920s. […] [It] created markets [for alcohol] that were blacker and more difficult for the federal government to deal with than [before]."

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However the regulation might be implemented, DIY-biology enthusiasts remain clear that their hobby is a positive development in a world that is witnessing the increasing application of genetic technology to health care, forensic science and public life. "I hope that demystifying the process will make others feel more comfortable with genetic tests; it's not magic, it's biochemistry," Aull commented. "That's a useful lesson, even though most people will choose a commercial provider instead of attempting DIY. […] But, as genetic testing extends into mainstream medicine, we need to encourage non-specialists to engage with this kind of information. Otherwise, the test is more scary than empowering."

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Howard Wolinsky

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